INNOVATIVE TECHNOLOGY
Summary Report

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Barometrically Enhanced Remediation Technology (BERT^{TM})

Industry Programs and Subsurface Contaminants Focus Area

Prepared for

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INNOVATIVE TECHNOLOGY
Summary Report

Barometrically Enhanced Remediation Technology (BERT™) and GPR

OST/TMS ID 2307

Industry Programs and
Subsurface Contaminants Focus Area

Demonstrated at
Idaho National Engineering and Environmental Laboratory
Radioactive Waste Management Complex Pit 2
Idaho Falls, Idaho

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

TABLE OF CONTENTS

1. SUMMARY	page 1
2. TECHNOLOGY DESCRIPTION	page 5
3. PERFORMANCE	page 8
4. TECHNOLOGY APPLICABILITY AND ALTERNATIVES	page 14
5. COST	page 16
6. REGULATORY AND POLICY ISSUES	page 20
7. LESSONS LEARNED	page 22

APPENDICES

A. REFERENCES	page A-1

SECTION 1

SUMMARY

Technology Summary

Problem

Many sites within the DOE complex are contaminated with volatile organic compounds (VOCs) at low concentrations. Frequently the contamination exists in the vadose zone near the surface and does not pose an immediate risk to the groundwater or other sensitive receptors. This type of contamination may not be considered a high priority problem, but does require some type of corrective action.

Solution

A low-cost, simple solution is being developed as an *in situ* containment and extraction methodology for sites where the volatile contaminants reside in the vadose zone. The approach capitalizes on wind effects and the vertical soil-gas movement resulting from natural barometric pressure oscillations, and harnesses this mechanism to ensure a net-upward, vertical soil-gas flux in the contaminated soil. The design is notable in that it requires no boreholes or site power, resulting in a low-cost, low-maintenance remediation system. This technology is applicable to sites where the contamination is volatile under standard conditions, resides close to the soil surface, and is of a sufficiently low concentration to eliminate the need for off-gas treatment. The approach is inherently inexpensive due to its passive design and low cost installation.

How it Works

Oscillations in barometric pressure are both diurnal, corresponding to daily heating and cooling of the atmosphere, and of longer time periods, resulting from the passage of weather fronts. Daily variations will average about 4 to 5 millibars (one millibar, mbar, is approximately one thousandth of an atmosphere) while those due to weather front passage can be 25 mbar or more. As the barometric pressure rises, a gradient is imposed on the soil gas, which drives fresh surface air into the soil. As it drops, gas vents upward from the soil into the atmosphere. The total movement of soil gas is dependent primarily on the magnitude and period of the pressure oscillations, the soil gas permeability, and the depth to an impermeable boundary. This boundary can be the water table, bedrock, or extensive layers of very low permeability material, such as caliche or clay. Since the fractional change in atmospheric pressure is small (typically 0.5 percent) the overall soil gas displacement during the daily cycle is also small (with an estimated range of centimeters to meters).

The Barometrically Enhanced Remediation Technology (BERT™) induces net upward displacement of soil gas using surface features that impede the downward movement of vapors, but allow upward movement. The system incorporates a surface seal, a plenum, and an extraction vent valve (Figure 1). Directly above the contaminant plume a layer of highly permeable material, such as pea gravel, is placed on the surface to form a collection plenum for the upward-moving soil gas. An impermeable membrane is placed over the collection plenum and extends outward over the soil surface to form a buffer zone, which controls the radial movement of air flowing into the soil during the high-pressure periods. The plenum is connected to the atmosphere with a high-volume vent valve, open only when soil gas is moving upward (during a drop in the barometric pressure). In operation the system ratchets the soil gas upward by allowing normal upward flow during barometric lows but restricts downward airflow during high-pressure cycles. The installation design also capitalizes upon wind effects, which induce a vacuum in the collection plenum and significantly increase the vent flow.

Advantages over Baseline

The baseline method for remediation of VOC contaminated soil in the vadose zone is excavation and landfill disposal. Soil vapor extraction (SVE) is also commonly used. BERT™ has the following advantages over these technologies:

- BERT™ is passive and inexpensive, yet prevents downward migration of soil vapor to the water table by assuring net upward movement
- BERT™ is non-intrusive and no boreholes are required for the remediation/containment process.
- The vented air is of sufficiently low VOC concentrations that, with respect to most state regulations, it can be released to the air without off-gas treatment.
- The technology remediates the soil as opposed to merely transferring owner's liability, which is the case with landfill disposal
- The design allows simultaneous use of the area for other purposes.
- The system requires no site power.

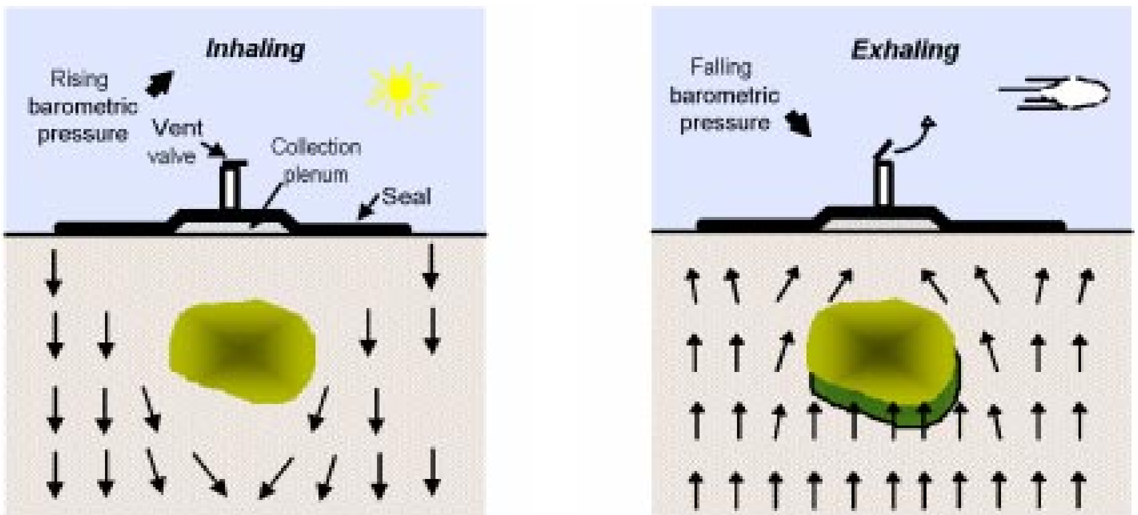

Figure 1. The surface treatment system controls the movement of soil gas due to barometric pressure changes.

Technology Status

This passive soil venting technology has been installed at the Idaho National Engineering and Environmental Laboratory (INEEL) Radioactive Waste Management Complex (RWMC) since December 1996. The system was upgraded in October 1998 to take advantage of wind effects and to increase the removal rate of VOCs. A visitors' day was held the week of November 16, 1998 to communicate the success of the demonstration to a wide audience and the demonstration concluded at the end of January 1999.

A BERT™ system is presently under construction at Los Alamos National Laboratory, with operation anticipated by the end of July, 1999. This installation will vent accumulated water vapor from beneath asphalt pads in a radioactive waste storage area.

Demonstration Summary

The INEEL RWMC is the site for the first demonstration of this barometric pumping remediation system. The Subsurface Disposal Area (SDA) is a 96 acre fenced disposal area inside the RWMC. Mixed wastes containing VOCs and radioactive wastes were buried at the SDA in shallow waste disposal pits, trenches, and soil vault rows (typically less than 20 ft deep). The geology of the SDA consists of surficial sediment deposits (ranging from 1 to 23 ft) overlaying thick basalt deposits. The surface soils consist of gravely sand and fine-grained eolian deposits. The water table is located approximately 600 ft below the ground surface. The bulk of the contamination detected during soil gas surveys is in the form of chlorinated hydrocarbons, primarily carbon tetrachloride (CCl_4), trichloroethylene (TCE), chloroform ($CHCl_3$), and tetrachloroethylene (PCE). The area chosen for this demonstration is identified as Pit 2.

The BERT™ demonstration system was installed at the INEEL RWMC in December 1996. The system operated continuously through the end of January 1999. The installation consists of a 100 ft square surface seal, with a 30 ft diameter collection plenum and vent system located at its center. The system is monitored continuously (at 45-minute intervals) for soil gas pressure and temperature, and two or four times daily gas samples are collected for oxygen and carbon dioxide analysis. Detailed soil gas surveys are conducted periodically to quantify the effect of the surface treatment system on the subsurface soil gas contaminant concentrations.

Evaluation of the monitoring data has resulted in the following observations:

- The system is extracting soil gas at a rate of twice that anticipated (as predicted by the barometric pumping process alone) likely due to the winds which occur at the same time as the drop in barometric pressure. Vent rates for the baseline system averaged 9 cubic meters per day (m^3/day), with peaks as high as 30 m^3/day. The predicted average vent flow rate was 4 m^3/day. After the system was modified to capitalize on wind effects, the vent flow increased to 34 m^3/day.

- During the coldest months (January and February) the system vent flow decreased, suspected due to freezing of the soil moisture beneath the plenum. After the soil temperatures rose above freezing, the vent flow returned to normal.

- Soil gas surveys show the vent system is releasing soil gas with contaminant concentrations diluted approximately 10 percent (compared to the soil gas 0.5 ft in the soil beneath the collection plenum), suspected due to horizontal leakage beneath the surface seal.

- The surface seal induced the desired controls on the subsurface soil gas pressure gradients. Beneath the center of the installation the gradients were predominantly upward, whereas in the uncovered soil they oscillated uniformly about zero.

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Web Site Locations

The Science and Engineering Associates, Inc. Internet address is http://www.seabase.com
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Licensing

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://em-50.em.doe.gov under “Publications.” The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference # for Barometrically Enhanced Remediation Technology (BERT™) is 2307.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

General

The BERT™ system utilizes a unique design incorporating a large-area surface seal, a collection plenum in the center of the surface seal area, and a one-way valve that vents the extracted soil gas to the atmosphere at a low rate. The system operation relies upon wind effects and the naturally occurring oscillations in barometric pressure, which range from 0.5 percent (in the case of diurnal variations) to over 2.5 percent (due to weather front passage) of the atmospheric pressure.

Changes in barometric pressure induce soil gas displacements in the unsaturated zone. Much like the movement of a piston in a cylinder, soil gas near the surface of the soil will displace downward if barometric pressure increases, and upward as barometric pressure falls (Figure 2a). Under steady-state conditions the displacement is proportional to the magnitude of the pressure change and the depth to a vapor-impermeable boundary, such as the water table. This would occur in a very high-permeability soil that allows immediate response of the soil gas pressure at depth to atmospheric changes. However, since soils have a finite permeability, the pressure response is attenuated in both time and magnitude, resulting in lower than ideal soil gas displacements. With depths to an impermeable layer of several hundred meters, expected displacements would be on the order of tens of centimeters to several meters.

Wind effects boost the system flow due to the vacuum induced in a pipe projected into a flowing air stream. Called the Bernoulli effect (Figure 2b), this process can remove significant volumes of soil gas from beneath the collection plenum.

Process Description

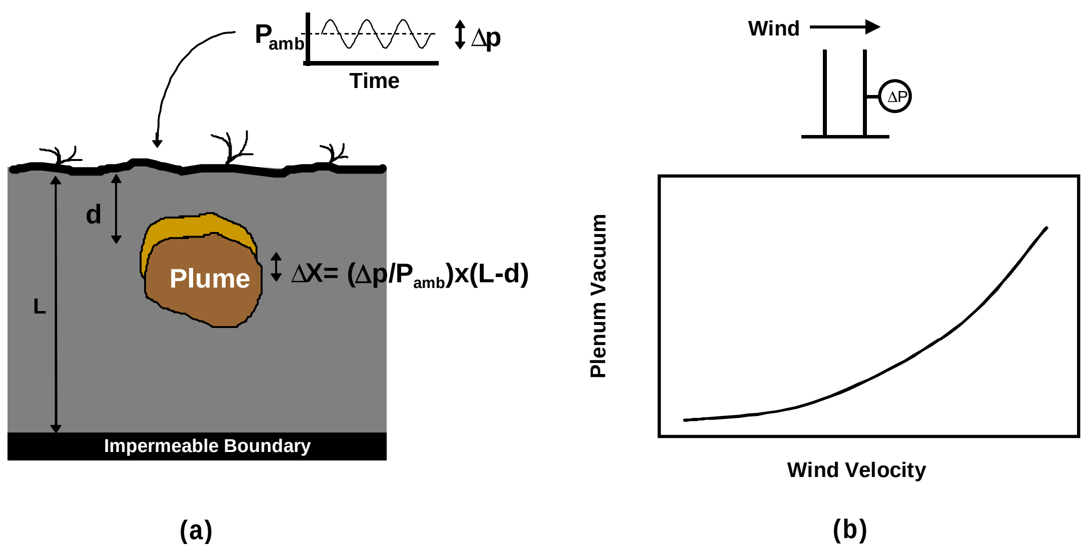

Figure 2. Processes that induce soil gas movement: (a) barometric pumping and (b) the Bernoulli effect.

Displacement of soil gas due to barometric pressure variations can be controlled using surface features that impede the downward movement of vapors, but allow upward movement. The design developed in this project incorporates a surface seal, a plenum, and an extraction vent valve. Directly above the contaminant plume is a layer of highly permeable material, such as pea gravel, which forms a collection plenum for the upward-moving soil gas. A surface seal is placed outward from the collection plenum directly on the soil surface to form a buffer zone that controls the radial movement of air flowing into the soil during the high-pressure periods. The surface seal is an impermeable, rugged material (such as a geotechnical membrane), which forms a no-flow boundary at the ground surface. The plenum is connected to atmospheric pressure with a high-volume vent valve, open only when soil gas is moving upward (during a drop in the barometric pressure). In operation, the system ratchets the soil gas upward by allowing normal upward flow during barometric lows but restricts downward airflow during high-pressure cycles. High-pressure periods result in restricted downward gas movement because the vent valve is closed and soil gas flows around the plume ("inhaling"). When the atmospheric pressure is lower than the soil gas pressure at depth, soil gas flows upward and the surface seal forces the contaminated gas into the plenum, where the opened vent valve exhausts it to the atmosphere ("exhaling").

System Components

In its installed form, the typical barometric remediation system is depicted in Figure 3. The key components are the surface seal, the plenum, and the vent assembly.

- Surface Seal: The role of the surface seal material is to contain soil vapors in the plenum region and prevent flow into or out of the soil in the buffer zone. Seal material must be resistant to soil moisture, organic contaminants, and sunlight (if exposed), and capable of multi year emplacements. Suitable membrane materials have been developed for roofing and landfill installations to fill requirements more stringent than these, so a wide selection of candidate materials is available. Ethylene-propylene-diene monomer (EPDM, commonly referred to as synthetic rubber) is very rugged and resistant to exposure and was selected for this application. The surface seal is one continuous sheet covering both the buffer zone and the plenum area. It must be pliable enough to conform to the contours of the soil (the soil will be leveled to some degree before the seal is applied) and over the plenum. To minimize damage to the geomembrane from abrasion (due to foot traffic), exposure to the elements, or plant/animal intrusion, a shallow layer of pea gravel is placed over the membrane. This serves a secondary role of assuring the membrane is pressed firmly onto the soil to promote a good seal.

- Plenum: The plenum serves as a collection manifold for the upward-flowing soil gas during the exhaling cycle of the system. Its basic requirements is that the plenum material have a permeability several orders of magnitude greater than the soil below. It must also be inexpensive, stable, and not pose a puncture threat to the membrane material (no sharp edges). Standard pea gravel fills these requirements with permeability in the range of 1000 to 5000 darcies (9.6×10^{-3} to 4.8×10^{-2} m/s). Since it has such a high permeability, a layer six to twelve inches thick is adequate.

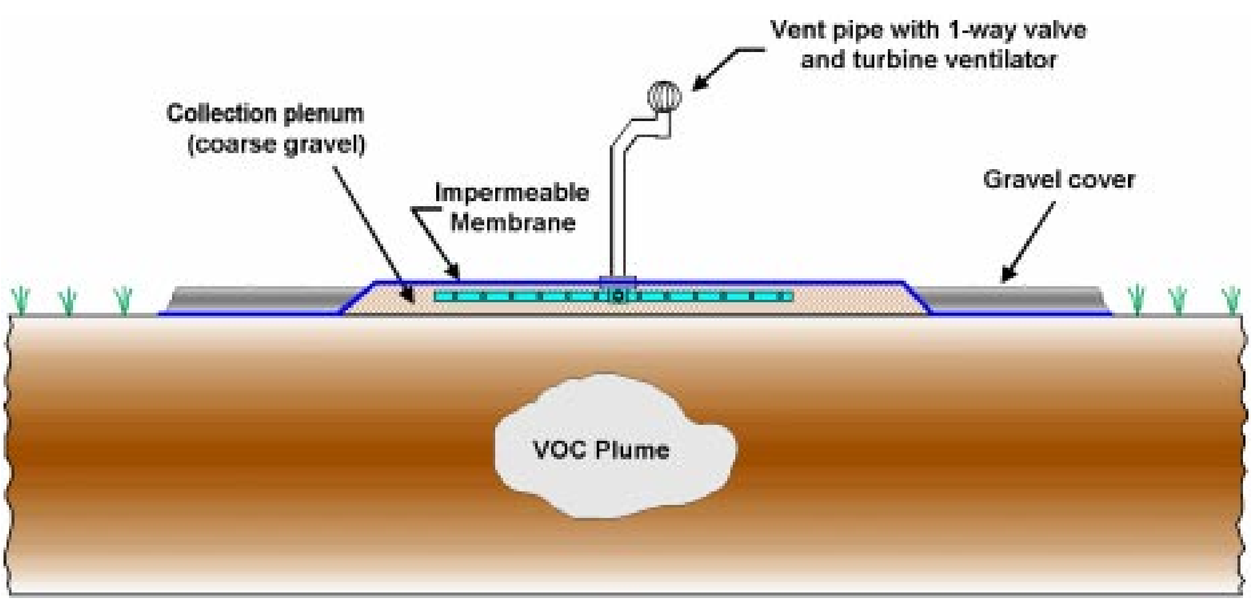

Figure 3. Typical field installation of BERT™ barometric pumping remediation system.

- Vent Assembly: The main role of the vent assembly is to allow only outward (exhaling) flow from the plenum volume. Its secondary role is to release the soil vapor high enough into the air to rapidly disperse the contaminants. The assembly consists of a vent pipe, a flapper valve, and a turbine ventilator. The surface seal membrane is clamped securely around the base of the vent pipe, which is free standing. The valve is a very low-differential pressure relief valve, designed to release soil gas at overpressures less than 0.1 mbar and provide very little backpressure when open. The turbine ventilator is an enhancement that capitalizes upon the surface winds to increase the extraction vacuum in the plenum. The vent valve is designed to operate at a minimal differential pressure while maintaining a seal when no positive pressure differential exists allowing for flow in one direction. The approach to the design is to mount a lightweight flapper valve inside the stack vent that will provide a seal by resting its mass on a sealing surface (Figure 4). The valve is oriented at an angle off of vertical, designed to open at the lowest differential pressure attainable (less than 0.1 mbar) yet still be strong enough to prevent backflow.

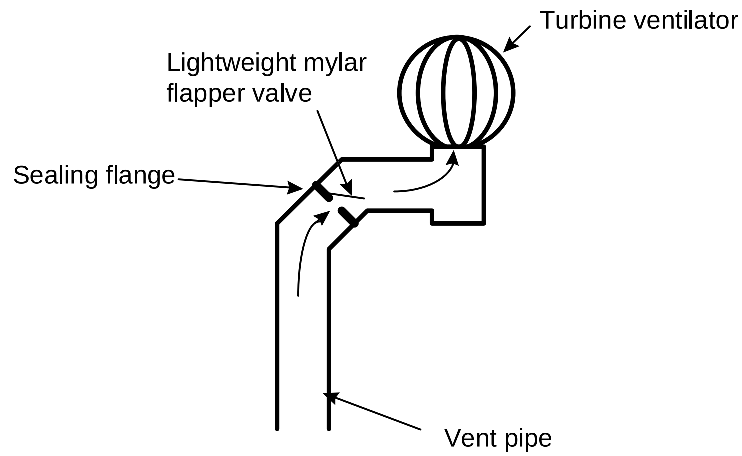

Figure 4. Relief valve and turbine ventilator configuration

System Operation

An automated monitoring system is not required for most installations and data can be collected manually. However, performance of the demonstration system installed at the RWMC is monitored by a solar powered, autonomous soil gas sampling and data acquisition system to obtain data for research and development. At 45-minute intervals the system records:

- In situ soil gas pressure (Setra Model 270 barometric pressure sensor)
- Atmospheric and plenum air pressures (same as above)
- In situ temperature (thermocouples)
- Wind speed (rotating vane anemometer)
- Ambient air temperature (solid state temperature sensor)
- Vent system outflow rate (low flow orifice plate flow meter)

On six-hour intervals, the system also samples soil gas and analyzes for oxygen (electrolytic cell) and carbon dioxide (non-dispersive infrared sensor). Manual gas samples are collected periodically and analyzed for the anticipated organic contaminants using a photoacoustic gas analyzer. Soil temperatures are measured at the same frequency as the soil gas pressure.

PERFORMANCE

Demonstration Plan

Idaho National Engineering and Environmental Laboratory Demonstration

The INEEL RWMC was selected as the candidate site for demonstration of the barometric pumping remediation system. The SDA is a fenced disposal area inside the RWMC. Mixed wastes containing volatile organic compounds and radioactive wastes were buried at the SDA. Included in the SDA are numerous waste disposal pits, trenches, and soil vault rows. The pits are backfilled excavations with a variety of dimensions.

The geology of the SDA consists of surficial sediment deposits overlaying thick basalt deposits. Irregularities in the soil thickness (ranging from 1 to 23 ft) reflect the surface undulations of the underlying basalts. The surface soils are typically less than 20 ft thick and consist of gravely sand and fine-grained eolian deposits. The water table is located approximately 600 ft below the ground surface.

The volatile contaminant vapor plume is believed to extend vertically from the ground surface to the surface of the groundwater at the depth of the aquifer. The bulk of the contamination detected during soil gas surveys is in the form of chlorinated hydrocarbons, dominated by CCl_4, with TCE, $CHCl_3$, and PCE in lower concentrations. Over the entire area of the SDA the peak concentration of any one component during the shallow soil gas surveys was about 1,000 ppm (detected in a 1987 survey near Pit 9). A recent shallow survey (1992) is depicted in figure 5, which shows the isopleths for carbon tetrachloride. The area chosen for this demonstration is identified as Pit 2. In the area of interest the peak contaminant concentration was 111 ppm of CCl_4. This disposal pit received barrels of sludge between 1954 and 1965.

Active vapor extraction is underway at the SDA using three extraction units. These extraction units are concentrating on volatile contaminants accumulated in an interbed at approximately 100 ft, a relatively thin layer of silty material between basalt units. Chlorinated hydrocarbon contaminant concentrations as high as 6,000 ppm have been detected in these zones, indicative of an accumulation of liquid contaminant. Unit C, the closest to the proposed demonstration site (approximately 250 ft distant), extracts from a 10-ft screened well interval centered on the 93-ft depth.
This area was selected for the demonstration because records indicate significant amounts of volatile

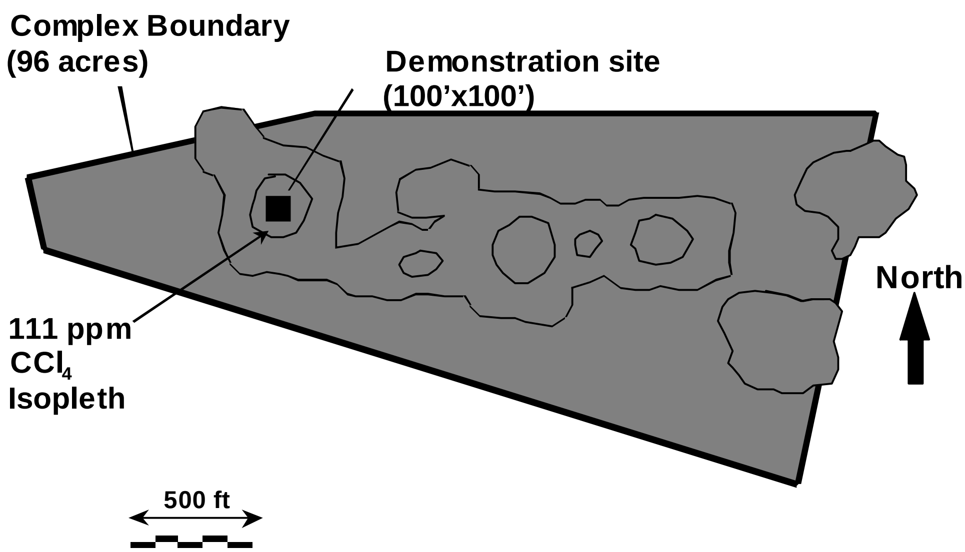

Figure 5. Demonstration site at INEEL RWMC.

contaminants were deposited in a well-defined area, soil gas surveys detected the presence of near-surface contaminant deposits, and the site has a deep water table to maximize barometrically induced soil gas displacements.

The installation of the remediation system required no excavation, although shallow penetrations in the soil were completed for soil vapor sampling. The site was cleared of vegetation, rocks, and debris prior to installation of the surface components. The vapor monitoring system required installation of soil vapor sampling points to a maximum depth of eight feet.

The installation was placed over the contaminated region of interest (see the plan view in Figure 6). In the center of the membrane is a collection plenum formed with a coarse pea gravel layer (10 inches thick) beneath the geomembrane. Located in the center of the plenum is a vent pipe, which allows soil gas collected in the plenum to vent to the atmosphere (Figures 7 and 8). The EPDM membrane is 100 ft square. The area of the surface seal radially outward from the plenum is covered with a layer of pea gravel to provide a positive seal to the soil and prevent movement of the membrane due to high winds. Around the perimeter of the surface seal, the membrane is anchored to plastic pipe. This serves as a positive anchor for the membrane perimeter and also prevents water runoff from the surface seal during heavy rains. The completed installation is depicted in Figures 9 and 10.

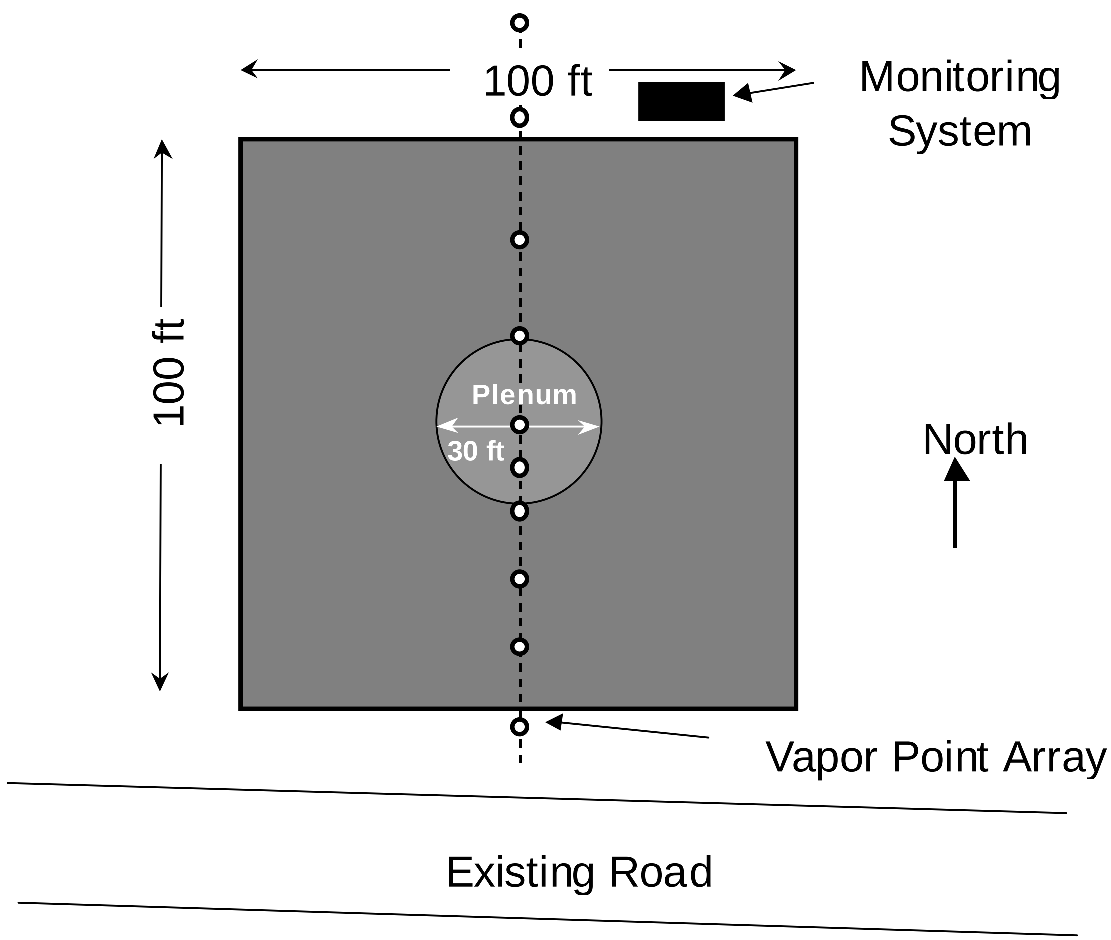

Figure 6. Plan view of BERT^{TM} installation over RWMC Pit 2.

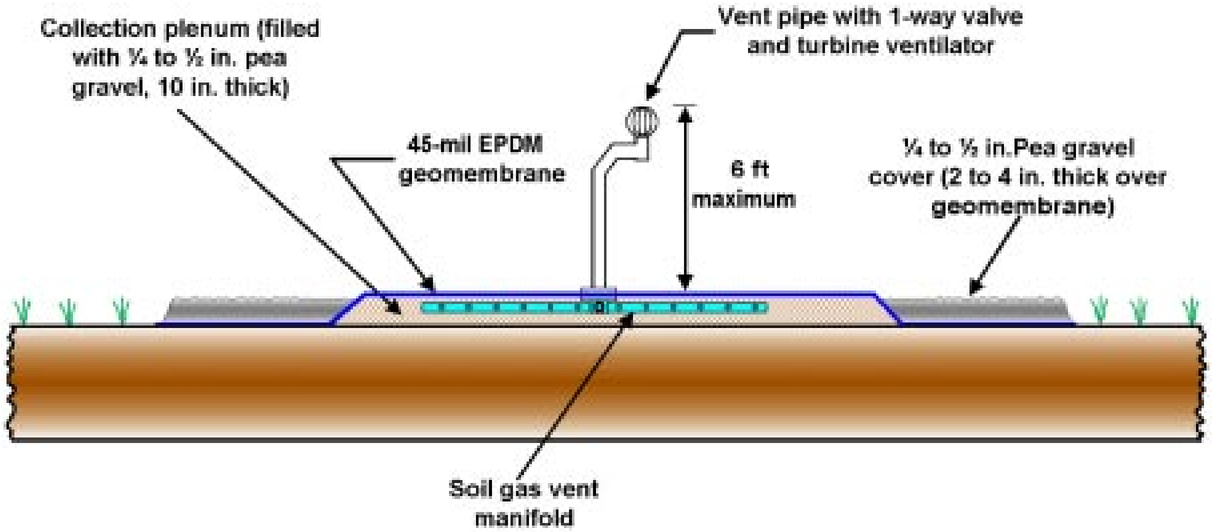

Figure 7. Vent pipe and original plenum configuration for demonstration at INEEL RWMC Pit 2.

Figure 8. Photo of installed vent system over Pit 2.

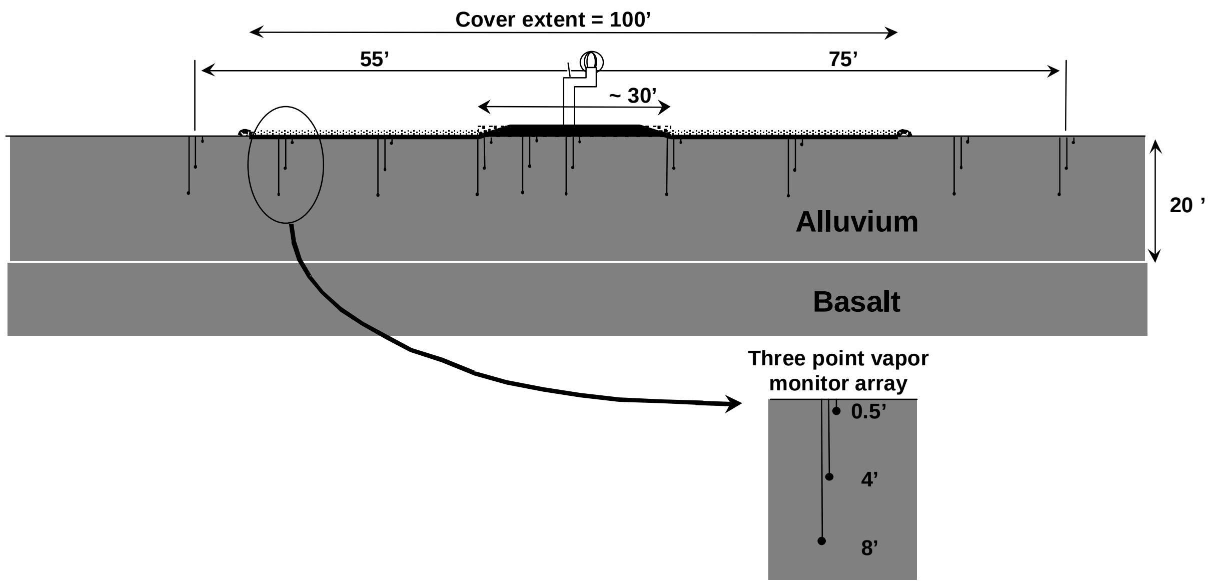

Figure 9. Vapor monitoring point installation design.

Figure 10. Completed BERT™ Installation in the spring of 1997.

Installation of the BERT™ system was completed on December 16, 1996. For the first two months of operation, the weather was particularly cloudy and the monitoring system was receiving insufficient sun to operate continuously. Consequently, test data was intermittent until early February, 1997, at which point the system began collecting data continuously. Key results indicated by the test data are listed below:

- The wind speed shows a much stronger correlation to vent flow than the change in atmospheric pressure versus vent flow plot, indicating that wind speed has a greater effect on the vent flow than drops in atmospheric pressure. Resulting flow both before and after system changes is plotted in Figure 11.

- The average vent flow rate over the operation of the original system configuration was 9.0 m^3/day. Sustained peak flows over a one-day interval were as high as 30 m^3/day. After the system was modified to capitalize on wind effects, the average flow increased to 34 m^3/day.

- The soil pressure underneath the vent pipe did not respond to rising barometric pressure, indicating the surface seal performed its desired function.

- A detailed soil gas analysis was performed prior to system installation, and again after five months of operation. High concentrations of contaminants are accumulating beneath the collection plenum. This can be due to two processes. The first is that the system is displacing the soil gas upward and consequently moving the plume up toward the plenum. The system is doing this to some degree, evidenced by the concentrations of contaminants in the vented air and the apparent concentrations higher beneath the plenum than the balance of the surface seal (Lowry 1998). However, high concentrations would accumulate under any impermeable sheeting placed over a contaminated site because the sheeting forms a no-flow boundary. It is likely that the accumulations are due to a combination of these two factors.

- Concentrations of contaminants in the vented air are typically 10 percent of the soil gas composition 6 inches beneath the plenum, indicating that the vented air is slightly diluted with air short circuiting beneath the surface seal membrane.

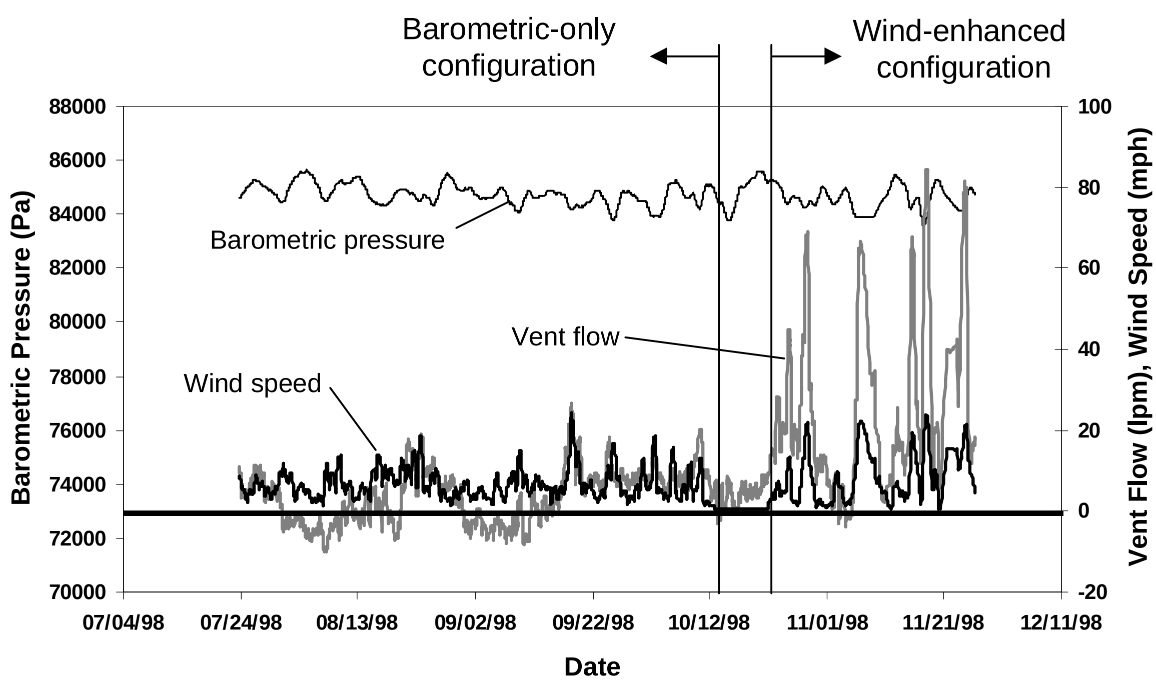

Figure 11. Vent flow, wind speed, and barometric pressure for the BERT™ system.

- The contaminant removal rates are determined by combining the vent flow rates with soil gas analysis, which included the gas in the vent pipe. Soil gas constituents were removed as indicated in Table 1.

- In October 1998 the system installation was modified to capitalize on wind effects. The collection plenum was extended to the edges of the surface seal (Figure 12), which maximizes soil exposure to the extraction vacuum. The mean vent flow increased from 9 to 34 m^3/day and the contaminant removal rate increased accordingly.

Table 1. Removal rates of contaminants

	Baseline (9 m^3/day)		**Wind enhanced (34 m^3/day)**	
Constituent	**Concentration (ppm)**	**Removal Rate (g/day)**	**Concentration (ppm)**	**Removal rate[1] (g/day)**
Trichloroethylene (TCE)	27.8	1.15	18.9	2.9
Carbon tetrachloride (CCl_4)	5.2	0.25	6.8	1.2
Chloroform ($CHCl_3$)	19.6	0.73	9.4	1.3
Carbon dioxide (CO_2)	65,000	903.2	14,500	761.1

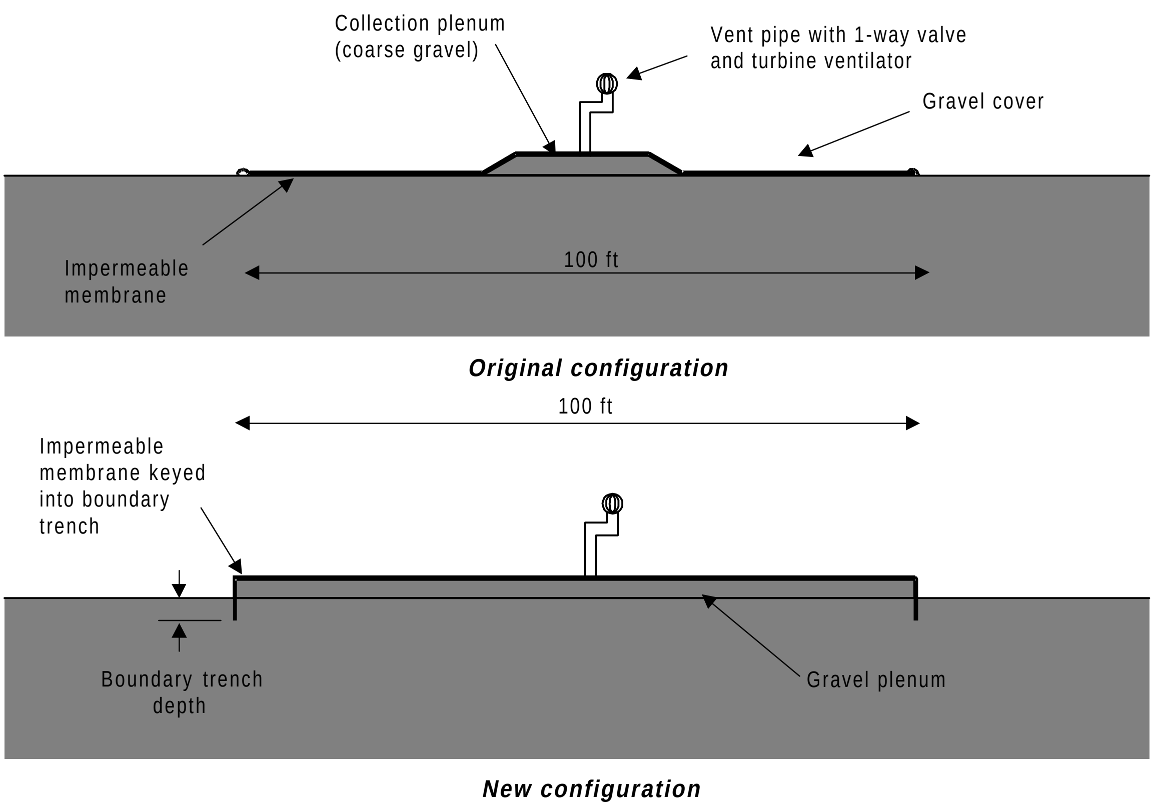

Figure 16. October 1998 modification of installation at RWMC Pit 2.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The baseline technology for remediation of VOCs in unsaturated soil is excavation and disposal of the contaminated soil at a licensed commercial landfill. Contaminated soil must be disposed of in a permitted landfill facility designed and operated in accordance with current Federal and state regulations. This method removes contamination from the subject site, but merely transfers the owner's liability from one site to another.

There are several competing technologies for the removal of VOCs from soil. Two of these competing technologies are:

- Soil vapor extraction (SVE) - This is an in situ process for the removal of VOCs from vadose zone soils. The typical system consists of a series of vapor extraction wells manifolded to a vacuum blower system with any required off-gas control. Installation of an SVE system may require subsurface modeling for well placement and/or a pilot field test. As opposed to BERT™, SVE systems apply an active vacuum to contaminated soils and the duration of remediation should be considerably shorter with higher air extraction and contaminant removal rates.

- Low temperature thermal desorption - This is an ex situ method of soil remediation designed to remove the organic contaminants from soil. The technology makes use of relatively low temperatures in the 300 to 600°F range. Prior to treatment, the contaminated soil is excavated from the site. Although, this technology has been less attractive in the past for projects with low volumes of soil, several vendors currently offer low temperature thermal desorption portable systems with small throughput (10-15 tons/hr). This technology may require off-gas controls and a more rigorous permitting process.

BERT™ is a novel application that will allow for inexpensive removal of VOC contamination in soils. Other soil gas removal technologies are designed to remove as much contamination as fast as possible; while a desirable goal, they are not cost-effective methods of removing contamination from less sensitive areas. In the arid west, the groundwater may lay hundreds of feet below the ground surface. VOCs that are contaminating the soil may take many years to reach the groundwater.

The system being demonstrated in this project uses passive technology to slowly, and inexpensively, purge volatile contaminants from the soil. Removal of contaminants occurs at such a slow rate that off-gas controls will not typically be required. In addition, the technology design results in virtually no waste generation (i.e., no drill cuttings) or resultant exposure to highly contaminated soils. Furthermore, the system requires virtually no maintenance or site power, and installations can be unobtrusive: parking lots and concrete pads can actually be part of the surface seal while allowing the land to be used for other purposes.

Table 2 is a comparison of baseline and competing technology advantages and disadvantages.

Technology Applicability

In general, application of the BERT™ system will be attractive approach if one or several of the following conditions are met:

- The plume is not posing a significant, immediate threat to water contamination. The liquid source is not migrating downward at a rate which could not be counteracted by this system.

Table 2. Comparison of Technologies

Technology	Advantages	Disadvantages
Landfill disposal	- Allows closure of the project site by removing contaminants - Excavation and disposal is fast	- Owner's liability is transferred from one site to another - Permanent contaminant destruction is not achieved - Workers are exposed to contamination
Soil vapor extraction	- Process applies an active vacuum and remediation time is relatively fast - Technology is proven and effective - Contaminants are removed and can be permanently destroyed - Treatment is in situ with little worker exposure to contaminants	- Requires a higher level of operator training with increased maintenance - Workers are exposed to more equipment/process hazards - Permitting and off-gas control may be required
Low temperature thermal desorption	- Process removes volatiles from soil through indirect heating and treatment is fast - Technology is proven and effective - Contaminants are removed and can be permanently destroyed	- Requires a high level of operator training and maintenance - Treatment is ex situ and workers are exposed to contamination - Permitting and off-gas control will be required

- The site has already been actively remediated (by vapor extraction, for example) but residual contamination exists. Incorporating this system can assure no residuals reach the water table, and it would remove residuals gradually over time.

- Usage of the site is not imminent. If, however, the site is a desirable location for a parking lot, the parking lot could perform the role of the surface seal.

Patents/Commercialization/Sponsor

SEA has been granted a patent for the BERT™ technology (number 5,893,680). The developer plans to license the system to firms involved in landfill design/construction and remediation. There is no commercial involvement from private industry at this point and SEA plans to independently privatize the technology with its licensees. Research has been sponsored by the DOE Office of Science and Technology, EM-50, through the Federal Energy Technology Center, Industry Programs. This project addresses the Subsurface Contaminants Focus Area need for dense non-aqueous phase liquid (DNAPL) remediation.

SECTION 5

COST

Methodology

Cost information for the BERT™ technology, as presented, is based on the actual field demonstration costs incurred at the RWMC Pit 2. Cost of a typical BERT™ installation will be low, primarily due to minimal site work, the lack of boring and/or well installation, and the elimination of treatment equipment. The primary equipment includes the EPDM sheeting, the plenum fill and seal cover gravel, the vent pipe assembly, supports, and vapor points. Optional equipment includes a continuous emissions monitoring system (not included in this estimate as contaminant removal rates will not likely warrant continuous monitoring).

To determine present value, capital costs for the BERT™ technology were escalated from the demonstration installation date (December 1996) to June 1999 using values from the Engineering News Record (ENR) Construction Cost Index (CCI). Long-term operation and maintenance costs were discounted to present value using Appendix C of Office of Management and Budget Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, assuming a 10-year project life. It is assumed that the system will be abandoned in year 10 with abandonment costs equal to the installation costs.

The baseline technology is soil excavation and disposal at a licensed commercial landfill. The competing technologies are soil vapor extraction and low temperature thermal desorption. Estimates for the baseline and competing technologies (Energetics 1999) were produced using R.S. Means *Environmental Remediation Cost Data - Assemblies, 4th Annual Edition* and escalated to June 1999 using the ENR CCI. A location factor of 0.85 was applied to the site. Startup costs and long-term operation and maintenance costs for these three technologies were capitalized due to the short duration of operation for each (i.e. less than 1 year). A description of assumptions for costing each technology follows.

Landfill Disposal

Primary costs associated with landfill disposal are trucking and disposal fees. Disposal fees can vary widely, depending on the type of the facility and the regional location. Prior to disposal, the contaminated soil is excavated from the site. Excavation includes the costs associated with handling and transporting contaminated soils from the site to the disposal facility. Costs for this baseline method include soil excavation, loading and transportation to a licensed hazardous waste landfill (less than 300 miles from the project site). Costs also include use of borrow soil from an on-site source to backfill the excavation.

Soil Vapor Extraction

Costs for this technology were estimated based on the installation of 5 vapor extraction wells screened to the bottom of the disposal pit (20 ft). Other costs include the disposal of drummed drill cuttings resulting from well installation at a licensed hazardous waste landfill, a vapor recovery system, an extraction blower, system manifold piping, miscellaneous fittings and equipment, and site deactivation and decommissioning. It is assumed that the remediation system operation period is 12 months and no off-gas control will be required due to the low VOC concentrations.

Low Temperature Thermal Desorption

Costs for this technology include site preparation, excavation of soils, material handling for treatment, use of a 10 ton/hr portable indirect fired unit, and replacement of treated soil in the excavation. It is assumed that the remediation system operation period is 1 month, VOCs can be destroyed in the afterburner, and no off-site disposal of residuals will be required.

For this cost study, a number of assumptions were used to define the RWMC Pit 2 site. The sample site is 30 ft in diameter and extends 20 ft deep to the bottom of the pit. This models the layout of the original plenum for the BERT™ technology demonstration at RWMC Pit 2. The contaminants of concern are VOCs located in the vadose zone. Characterization costs are not included here because they are common to any remediation system application. Costs do not reflect DOE oversight or contractor liability insurance.

The soil consists primarily of sand sized particles. Excavation of soils for disposal at a landfill or treatment using low temperature thermal desorption will result in 30 percent soil excess due to slope stability, and the soil density is 100 lb/ft^3. This results in 681 yd^3 or 919 tons of soil for treatment. This volume and weight is used in the Cost Analysis section to compare all remediation alternatives.

Work is accomplished using safety level D. Sampling costs to confirm remediation effectiveness are included to reflect requirements for an actual closure. Estimates assume that characterization has already been performed prior to remediation. Other cost factors include: site engineering/design/permitting at 10 percent of the project costs, overhead and profit at 15 percent, and project management at 10 percent.

Cost Analysis

Costs incurred by the contractor during BERT™ installation are reflected by the cost estimate summarized in Table 3. These line items are common to installation of the typical BERT™ system. Installation of 5 vents is included to reflect needs of a full-scale remediation system. The capital cost for BERT™ installation is $22,500.

Table 3. Cost estimate for remediation at RWMC Pit 2 using BERT™

Cost Item	Units	Quantity	Unit Cost ($)	Price ($)[1]
Materials:				
-Sealant: 45 mil EPDM sheeting	ft^2	10,000	0.55	5,780
-Plenum fill and seal cover gravel	yd^3	185	15	2,920
-Vent pipe, flapper valve, turbine ventilator, supports, and vapor points	Each	5	1,000	5,260
Labor:				
-Mobilization/demobilization	LS	1	1,000	1,050
-Surface grading/site preparation	hr	16	45	760
-Installation (cover, plenum and vent)	hr	128	50	6,730
Operation and maintenance				27,760
Subtotal				50,260
-Engineering/design/permitting (10%)				5,030
-Overhead and Profit (15%)				7,540
-Project Management (10%)				5,030
Total				67,860

[1] Price for Materials and Labor includes escalation from ENR CCI (12/96 = 5744 and 6/99 = 6039).

The anticipated operation and maintenance (O&M) cost for BERT™ is $2,000/yr for quarterly system checks and field analysis of the vapor sampling ports. The system decommissioning cost is assumed to equal the original installation cost ($6,730) at the end of year 10 and confirmation sampling after remediation is $6,890 (R. S. Means 1998, escalated to June 1999). The O&M costs were discounted at 2.7 percent (Office of Management and Budget 1992), yielding the a present value of $27,760. Applying the various factors results in an estimated present worth cost of $67,860 for remediating the subject site utilizing the BERT™ technology.

Table 4 summarizes the present worth cost of the baseline and competing technologies when compared to use of the BERT™ system at RWMC Pit 2.

Table 4. Comparison of baseline and other competing technology costs[1]

Landfill Disposal		Soil Vapor Extraction		Low Temperature Thermal Treatment	
Cost Item	Price ($)	Cost Item	Price ($)	Cost Item	Price ($)
Excavate soils/ load trucks	6,540	Install SVE wells	16,040	Excavate soils/ transfer to treatment	20,300
Transportation and disposal fees	143,370	Perform treatment using SVE	65,810	Thermal treatment of soils	144,900
Backfill/compact and grade site with borrow soil	7,660	Abandon wells and demobilize site	3,690	Backfill/compact and grade site with treated soil	7,150
Sampling and Analysis	3,770	Sampling and Analysis	6,890	Sampling and Analysis	9,260
Subtotal	161,340	Subtotal	92,430	Subtotal	181,610
Engineering/design/ permitting (10 %)	16,130	Engineering/design/ permitting (10 %)	9,240	Engineering/design/ permitting (10 %)	18,160
Overhead and Profit (15%)	24,200	Overhead and Profit (15%)	13,860	Overhead and Profit (15%)	27,240
Project Management (10%)	16,130	Project Management (10%)	9,240	Project Management (10%)	18,160
Total	217,800	**Total**	124,770	**Total**	245,170

[1] Prices include escalation using ENR CCI (composite 1998 = 5920 and 6/99 = 6039).

Cost Conclusions

Table 5 is a summary of estimated present worth remediation costs for RWMC Pit 2 when comparing the subject technology to the baseline and competing technologies. The order of magnitude unit costs are illustrated in Figure 13. Based on stated assumptions for each alternative, the following conclusions are presented:

- The analysis indicates significant cost savings when comparing the application of BERT™ to both baseline and competing technologies at RWMC Pit 2.
- Barometric pumping is a low cost alternative to other forms of remediation for unsaturated soils contaminated with volatile organic compounds.
- Similar cost savings could be realized for applications of BERT™ at other sites.

Table 5. Estimated costs of BERT™ and baseline/competing technologies

Technology	Present worth cost ($)	Cost/yd^3 treated ($)	Cost/ton treated ($)
BERT™	67,860	100	74
Landfill disposal	217,800	320	237
Soil Vapor Extraction	124,770	183	136
Low temperature thermal desorption	245,170	360	267

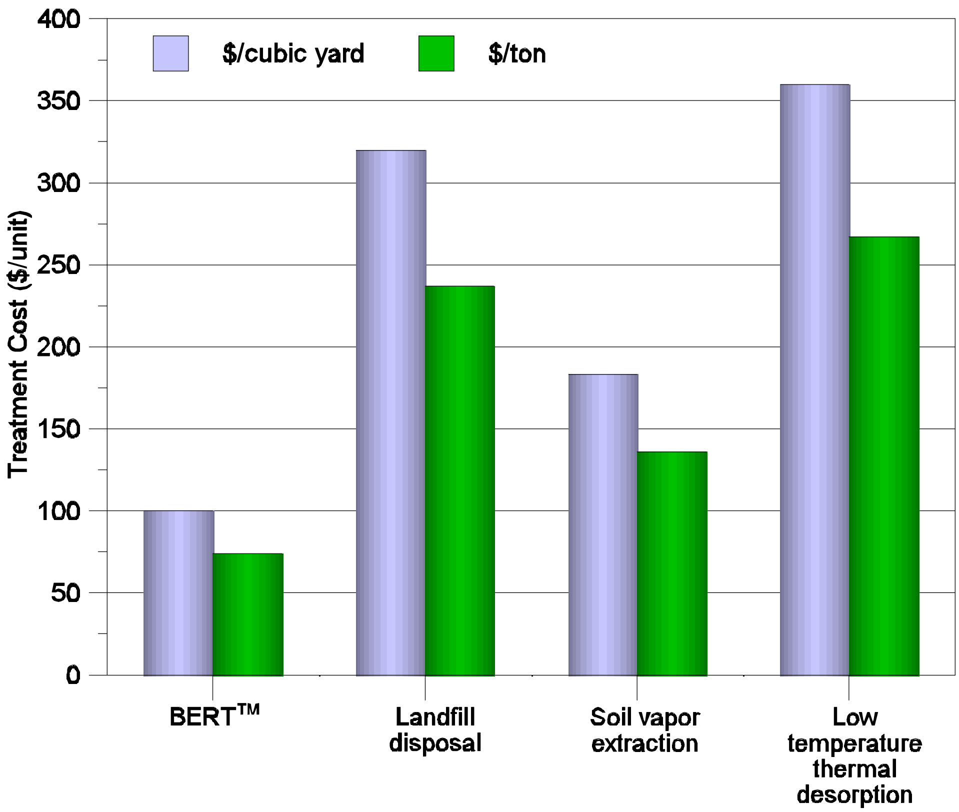

Figure 13. Technology unit cost comparison.

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

- The barometric pumping installation requires consideration of the atmospheric release limits imposed by local, state and Federal regulations. In the case of the INEEL installation, BERT^{TM} vents less than the point source release limits allowed by the State of Idaho for each contaminant. If the system production were to exceed the regulatory limits, air modeling would be required to ensure that the vented gas does not exceed allowable exposure limits to potential local receptors.

- Since the emission rate of contaminants is low, air emission controls may be avoided.

- Use of BERT^{TM} could serve as a low-cost alternative to “no action” scenarios under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) at sites having soils contaminated with VOCs, where contamination of groundwater is not imminent.

Some of the nine evaluation criteria for CERCLA remediation alternatives are discussed below. Other criteria, such as cost and effectiveness were discussed earlier in this document.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

- Health and safety issues for operation of the BERT^{TM} system are similar to those for soil vapor extraction with the exception that process equipment hazards are lessened when utilizing BERT^{TM}. Worker potential for exposure to airborne contaminants is also reduced with lower emission rates.

- Since BERT^{TM} is an in situ technology, workers are not exposed to excavated soils during remediation.

Community Safety

- Air emissions from BERT^{TM} are very low, compared to baseline and competing technologies, and should not impact the surrounding community.

- BERT^{TM} is an in situ technology and does not require soil excavation, thus lessening potential exposure to the surrounding community.

Environmental Impact

- BERT^{TM} does not require process/treatment equipment and produces no noise.

- No drilling or soil excavation is required. Grading for site preparation is minimal. Therefore, impact on air or surface water is minimal.

Socioeconomic Impacts and Community Perception

- BERT^{TM} will have a minimal impact on the local economy or work force.

- The general public has limited familiarity with BERT™; however, due to its similarities with soil vapor extraction which is commonly used for environmental cleanup, educating the public should be simplified. A Visitor's day was held at the RWMC Pit 2 demonstration site during November 1998 to familiarize stakeholders.

SECTION 7

LESSONS LEARNED

Implementation Considerations

The proposed system is applicable to near surface VOC contamination in the vadose zone. In general, this will be an attractive approach if one or several of the following conditions are met:

- The plume is not posing a significant, immediate threat to water contamination.
- The site has already been actively remediated (by vapor extraction, for example) but residual contamination exists. Incorporating this system can assure no residual contamination reaches the water table.
- Usage of the site is not imminent. If the site became a desirable location for a parking lot, for example, the parking lot could perform the role of the surface seal.
- Typical applications may include underground storage tanks, leaking buried pipelines, surface spills, or shallow landfills.

Technology Limitations

- BERT™ does not agressively remediate contaminated soils, as use of natural barometric effects along with the ventilator system limits the vent flow rate.
- Duration of cleanup using BERT™ will be substantially longer than baseline and competing technologies.
- The system is not applicable to saturated soils.

Needs for Future Development

In the development of this system it was expected that the barometric effects would dominate its performance. The data shows that wind effects, instead, provide significant boost to the system's performance. Wind boosts the collection plenum vacuum due to the Bernoulli effect, where a high velocity air stream passing across the end of a pipe will induce a vacuum in the pipe. The turbine ventilator is designed to enhance this effect. The area of the collection plenum limits the effects of the vacuum imposed by the wind. If the collection plenum area could be increased, air flow production would increase accordingly.

To investigate the effects an increased plenum area would have on air flow production, a numerical simulation was performed using the T2VOC code. A two-dimensional radial symmetric mesh was generated that represented the original configuration of the collection plenum and surface seal. The soil was modeled as a homogeneous medium, extending downward and outward from the system a sufficient distance to emulate the site scale. The numerical model was calibrated to match actual field conditions, then used as a predictive tool to evaluate different configurations of the collection plenum and surface seal with respect to air flow production. To calibrate the numerical model, the soil permeability was systematically changed until the resultant flow of air matched field measurements. Field test data indicated that, when the plenum was operating at a 15 Pascal (Pa) vacuum, the system flowed 15 liters per minute (lpm) vented air. This same vacuum was applied to the collection plenum area in the model, and the soil permeability which resulted in 15 lpm of vented air flow was 15 Darcies.

The numerical model was then used to predict air flow based on changes made to the configurations of the collection plenum and surface seal. The model's mesh was modified to represent a collection plenum 100 ft in diameter, with no additional surface seal. The outer boundary of the membrane, which contained the plenum, was keyed into the surface soil at varying depths. The model indicated that a 6-inch trench resulted in a flow of 86.8 lpm, and a 24-inch trench resulted in a rate of 71.6 lpm. The difference in flow between the two configurations is the air flowing from the atmosphere around the buried membrane.

Recommendations for design changes include: the gravel presently covering the surface seal should be removed, the surface seal should be rolled back, and a shallow 3- to 6-inch layer of pea gravel should be placed on the ground. The surface seal should be reinstalled over the gravel and its outer edged keyed into the soil to a depth of 6 to 12 inches. This should result in at least a 5 fold increase in vent air flow, and will not require any changes to the vent pipe and valve assembly. SEA is presently conducting tests to evaluate the production characteristics of different vent assemblies such as turbine ventilators, open pipes, and other vacuum enhancing attachments.

These changes were implemented in October 1998. The mean vent flow increased from 9 to 34 m^3/day, almost a factor of four. Evidence from the test indicate that increasing the number of vent assemblies on a given installation (i.e., 4 vent pipes instead of 1) would boost vent flows proportionally. Vent flows over a range of soil impedances are being evaluated to determine the performance characteristics of these systems, such that engineering design of the overall system is more quantitative.

Technology Selection Considerations

- Candidate sites include those with subsurface contamination in the vadose zone where site usage is not imminent.
- Use of BERT™ could serve as a low-cost alternative to “no action” scenarios under CERCLA.

APPENDIX A

REFERENCES

ECHOS. 1998. “Environmental Remediation Cost Data - Assemblies.” 4th Edition. R. S. Means Company, Inc., Kingston, MA.

Energetics, Inc. 1999. ”Baseline/Competing Technology Cost Assessment for BERT™”, Revision 1, Deliverable number U99A08089, Morgantown, WV.

Engineering News-Record [online],1999 [cited 24 June 1999]. “Construction Cost Index History (1908-1999).” Available from World Wide Web: <http://www.enr.com/cost/costcci.asp>.

Federal Energy Technology Center. 1998. “Standard Life-Cycle Cost-Savings Analysis Methodology for Deployment of Innovative Technologies.” Morgantown, WV.

Humphreys, K. K., and P. Wellman. 1996. “Basic Cost Engineering.” Third Edition, Revised and Expanded. New York: Marcel Dekker, Inc.

Lowry, W., S. D. Dunn, R. Walsh, J. Burmester, P. Zakian, and E. Cramer. 1996. "Barometric Pumping with a Twist: VOC Containment and Remediation without Boreholes: Phase I Final Report." METC Contract DE-AR21-95MC32109. Science & Engineering Associates, Santa Fe, NM.

Lowry, W., V. Chipman, and N. Mason. November 1998. “Interim Report: Barometric Pumping Remediation Demonstration at the INEEL RWMC Pit 2 Site,” Draft. FETC Contract No. DE-AR21-95MC32109. Science & Engineering Associates, Santa Fe, NM.

McCown, A., 1997. “Cost Savings Deliverables and Criteria for the OST Technology Decision Process.” Draft Version 1.4. Environmental Technology Cost-Savings Analysis Project (ETCAP), Los Alamos National Laboratory.

Millington, R. J. 1959. "Gas Diffusion on Porous Media." Science 103:100.

Office of Management and Budget. 1992. “Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.” Circular No. A-94, Appendix C [Revised January 1999]. Available from World Wide Web: <http://www1.whitehouse.gov/WH/EOP/OMB/html/circulars/a094.html>.

U.S. Environmental Protection Agency. Technology Innovation Office. 1996. “A Citizen’s Guide to Thermal Desorption.” EPA 542-F-96-005.

U.S. Environmental Protection Agency. Technology Innovation Office. 1996. “A Citizen’s Guide to Soil Vapor Extraction and Air Sparging.” EPA 542-F-96-008.